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Electrodynamic model of a storage pond dam

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Abstract

Introduction. *Geophysical exploration at a brine storage pond dam of Mirny Mining and Processing Division (MPD) were carried out in order to provide safe operation. A new approach to electrical logging data interpretation is based on past records generalization.*
Research aim *is to create a forecast electrodynamic model of a storage pond dam.*
Research methods included thermometry (measurements in the network of thermometric wells), piezometry (water level measurements in observation wells), land surveying (dam surface releveling), electrical resistivity tomography (aerial electrical exploration at a dam), and visual observations at a dam.
Results and analysis. *The regularities in electrical resistivity (ER) variation were determined at different depths in the three parts of a dam which were distinguished by the technogenic impact. Quantitative assessment of ER variations in different part of a dam was given depending on the thawing process time and the temperature of the environment. Calculation results and their interpretation were analyzed with the account of geological structure features of a hydraulic engineering structure.*
Summary. *The principles of forming a forecast electrodynamic model were created. A model for one storage pond dam was built as an example. The development of a generalized model for hydraulic engineering structures is possible if data from several sources is stored.*

Key words: *storage pond dam; electrical resistivity tomography; thermometry; forecast; electrodynamic model.*

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Geophysical exploration has been carried out at a brine storage pond dam on Alysardaakh stream of Mirny Mining and Processing Division (MPD) by a group of geophysicists, formed within the engineering survey department of Yakutniproalmaz Institute, ALROSA PJSC.

Research aim is to create a forecast electrodynamic model of a dam (FEDMD) of a brine storage pond. FEDMD describes dam rock electrical resistivity seasonal behavior as a result of thawing or freezing of its upper part.

Object of research is a composite-type rockfill dam (hereinafter hydraulic engineering structure HES), piled, inhomogeneous, freeze-thaw, maximum height – 35.5 m, crest length – 1010 m, crest width – 10 m, average back of dam slope – 1 : 3.95; downstream slope – 1 : 3.66. Main dam body has been filled with marl and diabase rock burden (fig. 1). Dam body is filled with crushed stone soil with sand-clay aggregate, which is a good barrier for groundwater. Dam center is filled with medium sand transmitting filtration flow of process water from the pond. Upstream and downstream banquette shells are filled with diabase crushed stone at the toe of a dam. Downstream banquette shell fulfills drainage functions.

In the region, daily mean temperature crosses zero in May and September. FEDMD describes only the indicated period of a calendar year. 300 m deep permafrost soil is everywhere around the dam. Seasonal temperature fluctuations of permafrost soil

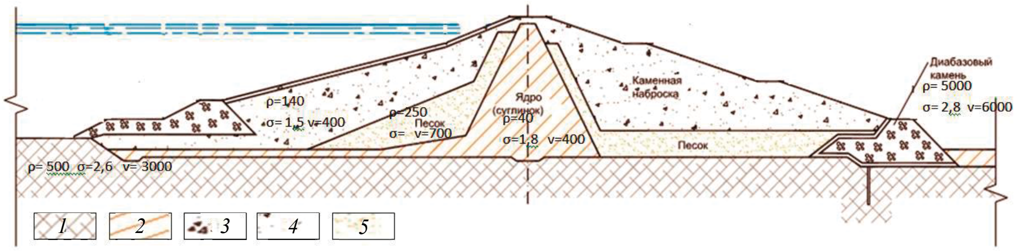

Fig. 1. Petrophysical model of a storage pond dam:
1 – limestone; *2* – loam; *3* – diabase rock; *4* – enrockment; *5* – sand
Рис. 1. Петрофизическая модель плотины пруда-накопителя:
1 – известняки; *2* – суглинок; *3* – диабазовый камень; *4* – каменная наброска; *5* – песок

attenuate at a depth of 9–11 m from the daylight surface. Consequently, FEDMD covers 15 m thickness upper near surface layer. With seasonal temperature variation, active layer and superpermafrost water freeze or thaw.

Subpermafrost water is at the depth of 310–315 m, it is head (up to 100 m) and briny, and of subzero temperature. Frozen rock ice content in friable deposits changes from 5 to 45%, and from 5 to 20% in hard rock and semi-rocky soil. Ice content depends

Table 1. Electrical resistivity of hard rock at freezing (according to V. S. Iakupov, changed), Ohm · m

Таблица 1. Удельное электрическое сопротивление скальных горных пород при промерзании (по В. С. Якупову, с изменениями), Ом · м

Rock, phase	ER of rock		ER growth at freezing
	permafrost	thawed	
Shale	900	140	6.5
Sandy shale	1200	–	–
Sandy schist	2000	250	8.0
Sandstone:	4000	410	9.8
diluvial-soliflual	33 000	–	80
alluvial, channel and old river bed facies	180 000	–	260
Glacial	500 000	–	400
Seasonally thawed stratum, permafrost	110 000	–	–
Lacustrine-alluvial deposits with syngenetic ice-wedge casts	1 330 000	–	2000

on the degree of rock jointing. Groundwater regime is controllable. There are siphons at the tailings storage which control water level. Mineralization of water solutions at HES reaches 117 g/l, which influences the results of geophysical exploration.

Research methodology. Water retaining structures study with geophysical methods goes back decades [1]. A new trend in electrical exploration is the creation of dynamic

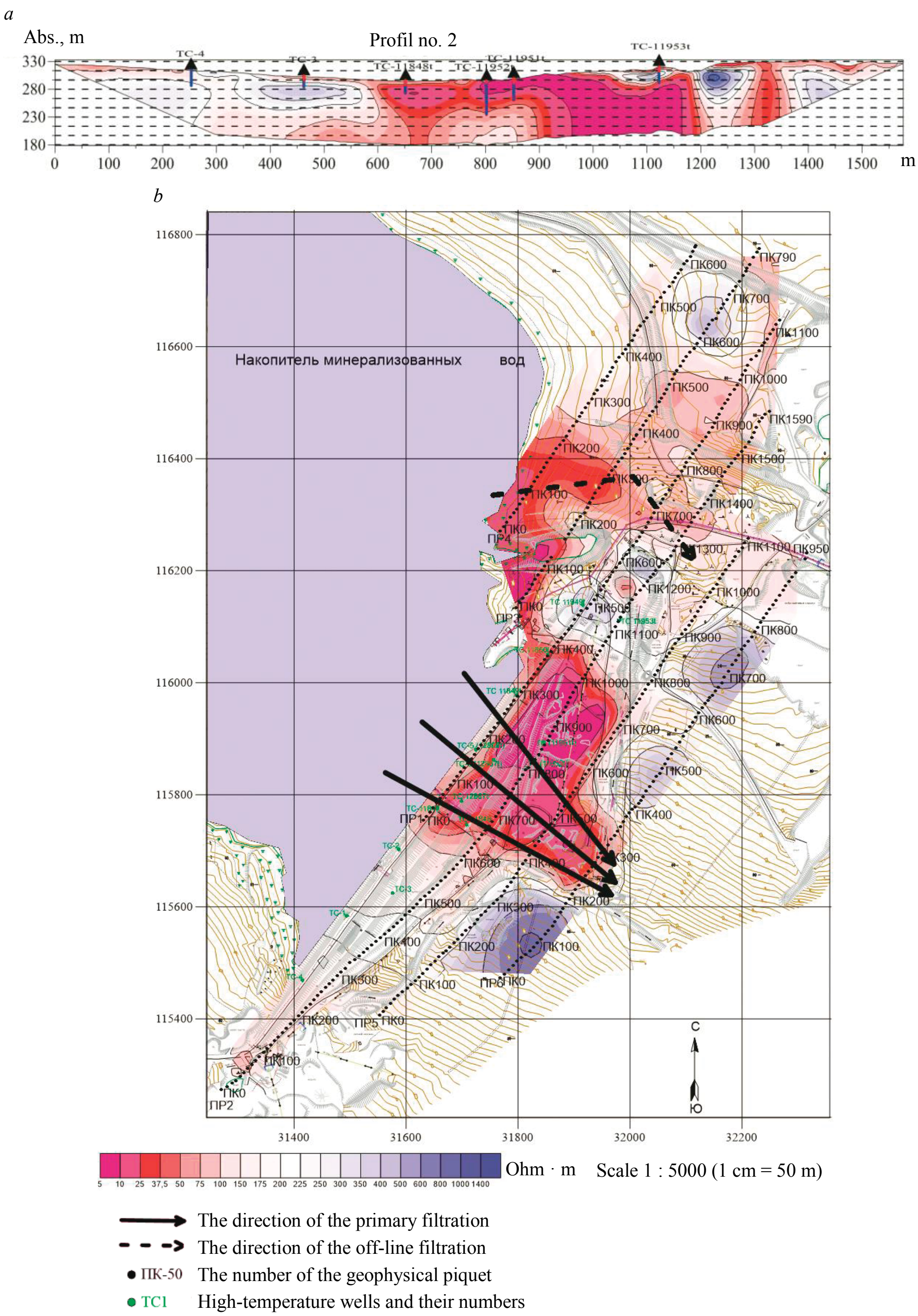

Fig. 2. Pseudodepth section – *a* and ρ_a isoresistivity map of a storage pond dam – *b*
Рис. 2. Псевдоэлектрический разрез – *a* и план изоом $\rho_к$ плотины пруда-накопителя – *b*

models based on regime electrometric measurements; it is applied in the Irkutsk and Perm regions [2–6]. The creation of dynamic models has become possible only when powerful computers and calculation data visualization tools appeared [7–10]. Works [10–13] are devoted to the study of karstification and geodynamic processes in engineering structures with the help of electrical logging. In [14], the principles of developing a forecast physical-dynamic model of karstification and caving are described.

In HES, there is a rapid change of material composition, phase, and physical properties. Temperature shift in a dam significantly influences its strength characteristics. The dependence between the electrical resistivity (ER) of rocks and the temperature is shown in the table 1. Electrical resistivity of soil depends on the lithological composition, water saturation, mineralization of solutions and on the temperature. Phase shift of a medium results in tenfold change of ER. These dependencies lie at the core of electrical logging application in HES state study. HES temperature is determined from electrical logging data, from which, in their turn, strength characteristics are determined.

The main geophysical method applied is electrical resistivity tomography. At the area of interest, six geophysical profiles were examined: at the dam of a brine storage pond, at the left-bank abutment of a storage pond, and at Alysardaakh stream landfall. For visual clarity, research results have been represented as pseudodepth sections and plans with isolines $\rho_a(h)$ at the depths of 10, 20, 30 m (fig. 2). Pseudodepth section at fig. 2, *a* reflects the inhomogeneity of the dam's structure vertically and horizontally, and the heterogeneity of backfilling [2].

In the course of HES operation, groundwater is concentrated with mineralized toxic waste. Water mineralization changes dam body rock ER significantly. Therefore, in order to determine the points of brine water leakage from HES, electrical resistivity tomography is used. Traditionally, electrical logging is applied at HES in order to solve the following tasks (fig. 2):

– determination of occurrence depth, thickness and the lines of lenses and horizons of brine water;

– determination of permafrost and thawed rock boundaries;

– outlining and determination of thickness of subgelisols and permafrost rock among the thawed rock;

– determination of groundwater and technogenic water discharge points, and water filtration points through the earthwork structures [4–10, 15].

Results analysis. By way of an integrated indicator characterizing the process of dam body seasonal thawing, τ – the thawing parameter from Stephan problem has been chosen:

$$\tau = \sqrt{Tt},$$

where *t* is the timespan from the day mean air temperature transition from subzero to above-zero to the start of geophysical exploration; *T* is the day mean temperature; τ reflects the amount of heat transferred from air to the subsoil.

At fig. 3 dependency graphs of apparent resistivity and the depth $\rho_a(h)$ are shown for different values of the thawing parameter. $\rho_a(h)$ reflects the phase state of rock and the level of water mineralization. Only the upper 15 m thickness layer has been considered which goes through seasonal thawing and freezing of soil. The represented data point to the different character of thawing in the left abutment of a dam, the central part, and the right abutment; it reveals different compositions and structures of these parts of a dam. Left and right abutments contain natural soil, the central part contains artificial structure. The central part thaws not like left and right abutments. In left and right abutments, $\rho_a(h)$ dependencies are direct and linear, while in the central part,

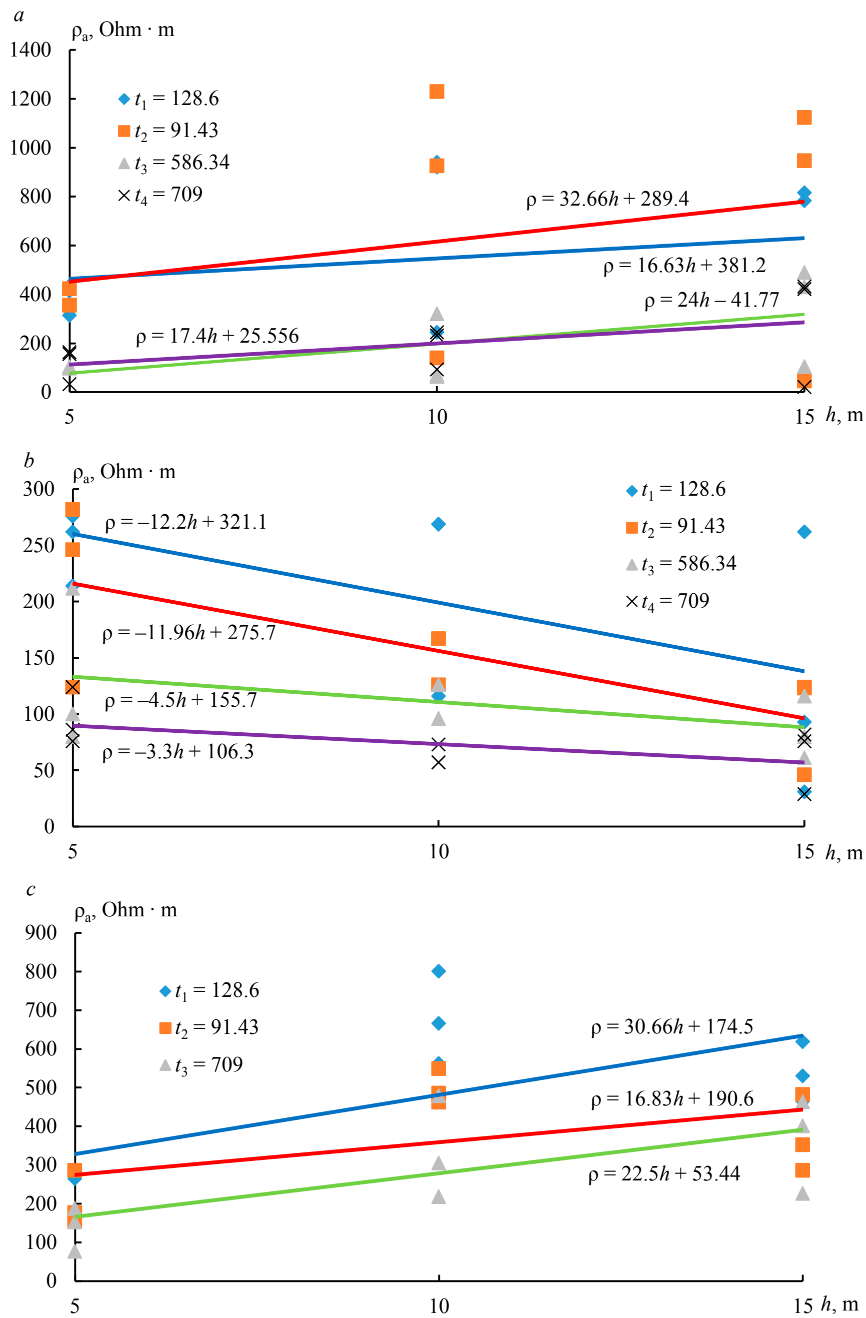

Fig. 3. Dependency graphs of apparent resistivity and the depth for different values of the thawing parameter:
a – for left abutment; *b* – for the central part of a dam; *c* – for right abutment

Рис. 3. Зависимости кажущегося сопротивления от высоты при разных значениях параметра растепления:
a – для левого примыкания; *b* – для центральной части плотины; *c* – для правого примыкания

$\rho_a(h)$ dependency is inverse and linear. This fact caused further separate study of measurement results in different parts of the dam and FEDMD representation as a model consisting of three arts. In the zones of transition from the central part to the abutments, ρ_a does not depend on depth.

In HES right and left abutments, primary rock is least subject to technogenic shifts. Fig. 4, *a* shows dependency between ρ_a and the thawing parameter in the left abutment of a storage pond at various depths. Each point on a graph has come out of averaging ρ_a according to 5–10 adjacent measurement points in the left abutment, which improves the reliability of the obtained dependencies. The deduced dependencies quantitatively characterize the process of dam body thawing. As the thawing parameter τ grows, ρ_a in the upper near surface layer decreases to the depths of 10–15 m, which is conditioned by the thawing depth increase. For example, as of 2014–2015, at the beginning of the summer season, mean value of ρ_a at 5 m depth was 400 Ohm · m. In 2017–2018, works were carried out at the end of the summer season, and at the same depth the mean value of ρ_a was about 130 Ohm · m. At the depths of 10–15 m this influence is not that big, but the inclination towards the increase in conductivity with the increase in the thawing parameter holds. ρ_a for the corresponding values of τ in the right and left abutments are twice as high as in the central part of a dam.

Apparent resistivity of the central part of a dam is significantly lower than in the left and right abutments. In the central part of the structure, filled with medium sands and more subject to seasonal shifts, dependency $\rho_a(h)$ remains significant at the depth of 15 m, at the same time, the dependency is characterized by a more significant fall of resistance (fig. 4, *b*). Thawing in the central part of a dam is more intensive than in the abutments.

In the central part of a dam, ρ_a falls with the growth of depth, which is due to the presence of brine water; ρ_a falls with the growth of the thawing parameter. In the left and right abutments, ρ_a grows with the growth of depth; ρ_a falls with the growth of the thawing parameter.

The results of multiyear research are in the core of HES forecast electrodynamic model aimed at its diagnostics in the following years. As soon as the object of research is situated in the zone of permafrost, the main factor influencing physical and mechanical properties shifts is the temperature regime. Geophysical exploration was carried out in different periods of time and, consequently, with different thawing timespan prior to measuring.

Data of different years prove the stable nature of $\rho_a(\tau)$ dependencies at similar seasonal thermal processes. For example, graphs $\rho_a(\tau)$ for 2016 and 2017 are almost the same. The averaged dependencies of the two years may therefore be considered a standard, in relation to which the data of electrical resistivity tomography of other years will be examined. The obtained dependencies represent the forecast electromagnetic model of a brine storage pond at on Alysardaakh stream of Mirny MPD. The results of measurements obtained in the conditions of abnormally hot summer season should be compared with this model.

Summary. The obtained dependencies $\rho_a(\tau)$ for different parts of the storage pond open an opportunity of medium phase forecast (fig. 3). HES electrodynamic model has been created according to the experimental data of several years. This model may be considered a standard for HES state monitoring.

With the help of the developed model, according to the data from electrical resistivity tomography, the deviations from the thermal process (thawing) from the stated standard can be determined. The presence of significant deviations from FEDMD require integrated geophysical and repair and renewal operations at the facility.

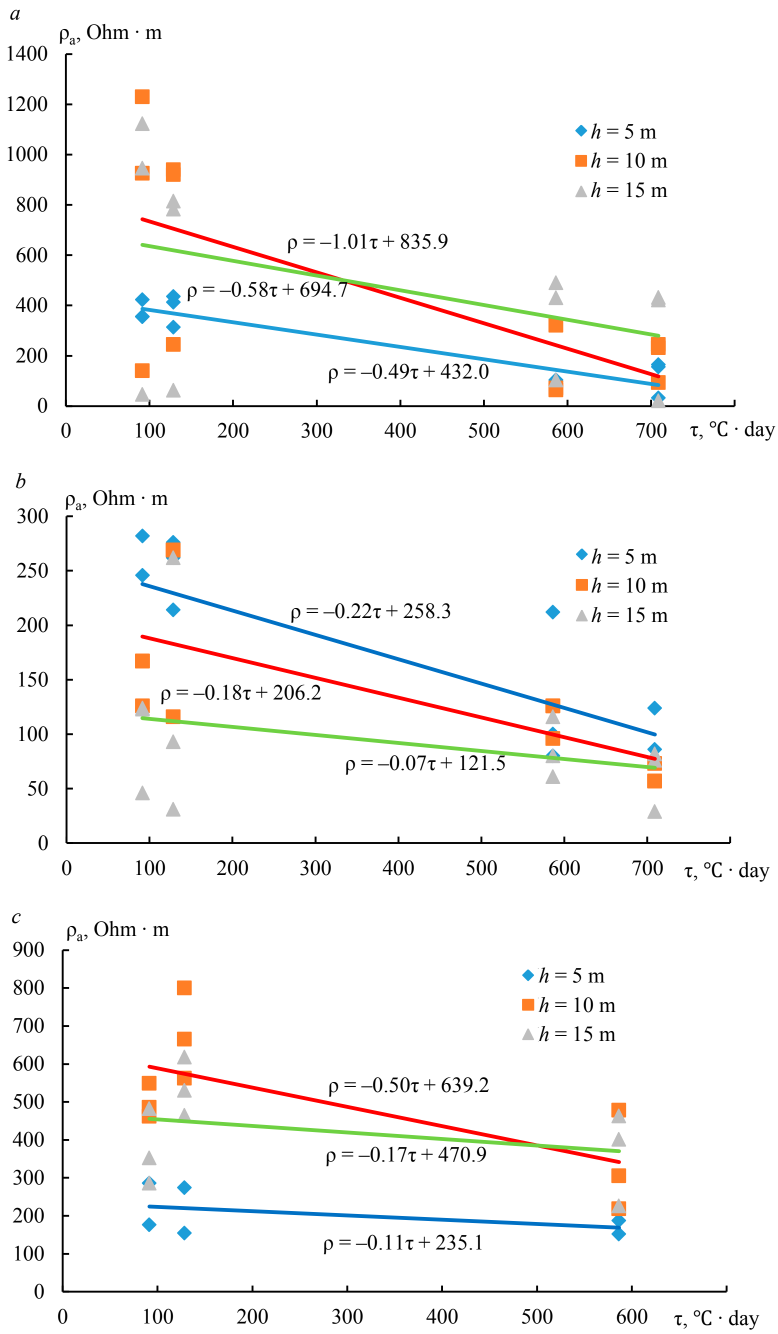

Fig. 4. Dependency between apparent resistivity and the thawing parameter at various depths:
a – left abutment; *b* – central part; *c* – right abutment

Рис. 4. Зависимости кажущегося сопротивления от параметра растепления при разной высоте:
a – в левом примыкании; *b* – в центральной части; *c* – в правом примыкании

To make the model complete, geophysical exploration should be carried out in the middle of the summer season (in June) within the following 2–3 years. The obtained dependencies will be made more accurate as far as the new data is stored. Further research should be focused on this type of tasks solution at other facilities of the Mirny region in order to control thawing and freezing of HES.

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Электродинамическая модель плотины пруда-накопителя

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Реферат

Введение. *Геофизические работы на плотине пруда-накопителя минерализованных вод Мирнинского ГОКа проведены для обеспечения безопасной работы ГОКа. Новый подход к истолкованию данных электрометрии основан на обобщении материалов прошлых лет.*

Цель работы *– создание прогнозной электродинамической модели плотины пруда-накопителя.*

Методы исследования. *Термометрия (измерения в сети температурных скважин), пьезометрия (измерения уровня вод в пьезометрических скважинах), маркшейдерские работы (повторное нивелирование поверхности дамбы), электротомография (проведение площадных электроразведочных работ на дамбе), визуальные наблюдения на дамбе.*

Результаты и их анализ. *Установлены закономерности изменения удельного электрического сопротивления (УЭС) на разных глубинах в трех частях плотины, отмеченных техногенным влиянием. Дана количественная оценка изменений УЭС разных частей плотины в зависимости от длительности процесса растепления и температуры окружающей среды. Проанализированы результаты расчетов и их интерпретация с учетом геологических особенностей строения гидротехнического сооружения.*

Выводы. *Создана методика формирования прогнозной электродинамической модели. Приведен пример создания модели для одной из плотин пруда-накопителя. Методика может быть применена на других объектах. Создание обобщенной модели для гидротехнических сооружений возможно при накоплении данных по нескольким объектам.*

Ключевые слова: *плотина пруда-накопителя; электротомография; термометрия; прогноз; электродинамическая модель.*

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